PROCEDURES FOR THE ANALYSIS OF THE DEBRIS PRODUCED BY EXPLOSION EVENTS*

prepared by

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ABSTRACT

Questions often arise as to the proper procedures to apply to the collection and analysis of the debris produced by explosive events. This paper recommends a standardized set of collection and analysis procedures which should be applied to both the debris produced by accidental events and the debris produced by planned explosion tests. Sample calculations which demonstrate the methodology are presented.

BACKGROUND

At the request of the Department of Defense Explosives Safety Board (DDESB), the Naval Surface Warfare Center (NAVSWC) has established and proposes the methodology defined in this paper to "standardize" the analysis of debris for purposes of quantity-distance safety criteria analyses.

The goal of the debris analysis described here is the determination of the hazardous fragment distribution (density) and the maximum debris throw range. The DDESB defines a hazardous fragment density as "A density of hazardous fragments exceeding one per 600 sq. ft. (55.7 m^2)"[1] A hazardous fragment is defined as "one having an impact energy of 58 ft-lb (79 Joules) or greater." A crucial question is the interpretation of one per 600 sq. ft. Is the 600 ft^2 measured along the ground surface, on vertical targets, or along a line which is normal to the trajectory?

Recent interpretations by the Secretariat of the DDESB have taken the 600 ft^2 to be measured trajectory-normal. This is difficult, if not impossible, to determine experimentally. Ground surface data, on the other hand, is straight-forward to obtain. To facilitate the computation of a "pseudo-trajectory-normal" density, the DDESB has proposed the following procedure: The number of hazardous debris pieces within a recovery zone will consist of the number of pieces of hazardous debris actually collected within the zone as well as the number of hazardous pieces passing through the zone and landing at a greater distance. For example, consider a 5° recovery sector which is divided into 100-foot increments. The total number of hazardous fragments in the sector between 500 and 600 feet would consist of the hazardous material found in that sector plus the hazardous material found beyond 600 feet; the next sector (600-700) would contain consist of all the material in that sector added to the material located beyond 700 feet.

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TRAJECTORY-NORMAL VERSUS GROUND SURFACE PICK-UP

How valid is the procedure described above for generating a reasonable approximation to trajectory-normal data from ground surface pick-up? The two methods can be compared in two ways--through the use of experimental data and through the use of computer simulation. Unfortunately, the experimental data base is relatively limited. As part of warhead or weapons evaluation tests, fragmentation arenas are used to sample the near-field (within 100 feet of the point of the detonation) fragmentation patterns. When far-field collections are made, they have, predominately, relied on ground surface pickup. Thus, we are limited to computer simulations.

The computer program FRAGHAZ[2] was used to generate debris densities as a function of range for four systems: (1) Weapon A (based on an arbitrary number of MK 82 bombs), (2) Weapon B (based on an arbitrary number of 155 mm projectiles), (3) Weapon C (based on an arbitrary number of 5"/54 projectiles), and (4) Weapon D (based on an arbitrary number of 105 mm projectiles). The FRAGHAZ program uses near-field arena data and calculates individual trajectories for each fragment. Because complete trajectories are generated for each fragment, both the ground surface density and the trajectory-normal density can be determined.

Figure 1 graphically illustrates the problem of ground surface density versus trajectory-normal densities. Each graph has been normalized to its own maximum fragment range, and presents the ratio of the trajectory-normal densities to the ground surface densities. One would expect this density ratio to approach 1 as the range approaches the maximum range. Indeed, this is the case. However, even at the maximum range (R/R_{max} =1.0), the trajectory-normal densities are significantly higher than the ground surface densities. At ranges less than the maximum range $R/R_{max} < 1.0$, the density ratio is much greater than 1. Hence the need to, somehow, estimate the trajectory-normal densities from the ground surface densities.

The same FRAGHAZ runs used to generate the data for Figure 1 were also used as input data for calculations of hazard range for both trajectory-normal and ground surface pickup (for these calculations, all fragments were considered hazardous). The procedures outlined in the following sections were used to calculate the debris range. The results are presented in Table 1. In each case, the pseudo-trajectory-normal densities (estimated from the ground surface data) over estimated the density by 8.1 to 15.9%--with an average 12.2%. Thus, this approximation technique appears valid--yielding realistically conservative estimates of the trajectory-normal densities.

GENERAL GUIDELINES FOR DEBRIS ANALYSIS

These guidelines can be broken down into two parts--(1) those that apply to planned tests--a part of which is debris collection and analysis and (2) those that apply to debris investigations of unplanned events.

Planned Tests

(1) Survey 5° debris recovery sectors in each significant direction. Make sure these sectors are clear and smooth out to a distance of at least $50W^{1/3}$ feet , where W is the explosive weight in pounds (19.8 $Q^{1/3}$ meters, where Q is the explosive weight in kilograms). If the real estate is available, these sectors should extend out to $75W^{1/3}$ feet (25.8 $Q^{1/3}$ meters). A minimum of three directions is required.

(2) Divide and mark each 5° sector into known range increments (a minimum increment of 5 meters is required; the maximum increment should not be greater than 30 meters). Each recovery sector should have a surface area of at least 100 m^2.

(3) Provide sufficient high speed camera coverage to allow reliable estimation of fragment initial velocities and launch angles.

(4) For each range increment of each 5° sector, where feasible, recover, bag, and label all the debris material found within the increment. If it is not feasible to recover particular debris pieces, treat them in the same manner as the material in Step (5).

(5) Survey the locations of all significant debris pieces located outside the 5° sectors. For each piece record its location (range and azimuth from ground zero) as well as its description (length, width, thickness, mass, and type of material). A general rule of thumb is that if you can see it, then it is a piece of significant debris. Photographs of each significant piece may also be necessary.

(6) Determine a minimum debris size for the particular test. For example, all material with a weight of less than 1.0 grams might be excluded; similarly, all material whose length, width, or thickness is less than 5 mm might be excluded. Screen all of the material collected in the recovery sectors. The material that is larger than the minimum debris size should be weighed and have its length, width, and thickness and type of material determined.

(7) For each recovery sector, determine which debris pieces are hazardous. One method would be to utilize a series of trajectory calculations to determine the minimum debris size which could have an impact energy of 58 ft-lbs (or whatever energy threshold is decided upon).

(8) Within each 5° sector, calculate the numbers of pseudo-trajectory-normal hazardous fragments. For a given recovery zone within a particular 5° sector, this is simply the number of hazardous fragments landing in that zone and in all zones beyond.

(9) Once the numbers of pseudo-trajectory-normal hazardous fragments have been obtained, generate a function which gives the number of hazardous fragments per 600 ft^2 as a function of range. This function should be of the form :

$$D=Ae^{BR}$$

where D = Fragment Density (Number of hazardous fragments per 600 ft^2)
R = Range
A,B = Fitting Constants.

Once this fit has been obtained, solve for the value of R which gives a fragment density, D, equal to one. This, then, is the debris hazard range for that particular set of data.

(10) Prepare two debris maps--one showing the locations of all debris and the second showing the locations of all hazardous debris. Show on these maps the computed debris hazard ranges.

(11) Prepare a computerized "debris catalog". This should contain an entry for every fragment that is recovered. This entry should include the location (range and azimuth from ground zero), description, and whether or not it was determined to be hazardous.

(12) Prepare a mass distribution (fragment/debris mass versus number of pieces with that mass or greater) based on the recovered debris.

Unplanned Events

(1) Obtain photographic coverage of the area; this should include photographs of all major pieces of debris.

(2) Determine the location of every piece of significant debris (If you can see it, then it is significant). For each piece, record its location (range and azimuth from ground zero) as well as its description (length, width, thickness, mass, and type of material).

(3) Prepare a computerized debris catalog and map of all recovered material.

(4) Set up analysis sectors on the computerized debris maps. Sufficient sectors should be chosen to show any azimuthal variations in debris density. These sectors should have a minimum width of at least 5°.

(5) Go to Step 7 for "Planned Events" and continue to analyze each 5° sector, paying special attention to those sectors with the highest concentrations of material.

SAMPLE CALCULATIONS

Two sets of data are presented as examples on the use of this methodology. Both are based on the results of accident investigations.

Processing Building Accident

At the 1988 DDESB seminar, results were presented on the analyses of the debris produced by a processing building accident.[3] At the time, it was estimated that the accident was equivalent to the detonation of approximately 4200 pounds of TNT. Subsequent to the publication of the paper, the analysis procedures presented above were finalized and accepted by the Secretariat of the DDESB. Therefore, this data will be re-examined using the new procedures.

Table 2 presents the "raw data", as collected at the accident site. Each cell corresponds to a recovery area of 100' x 100'. The shaded area near the center represents the approximate location of the building itself. Where a fragment was found on the boundary between two cells, it was split between them.

Fifteen degree azimuth lines were overlaid on this data and the numbers of fragments along each azimuth were computed. Table 3 gives this data as a function of azimuth around the structure (0° corresponds to a direction of East) (Note: Trajectory calculations indicated that all debris should be considered as hazardous).

Table 4 presents the pseudo-trajectory-normal densities as a function of azimuth and range. These were calculated according to the procedures described above. The application and solution of the curve fitting procedures results in the information presented in Table 5 and Figure 2.

There were two features at this site that should have caused reductions in the debris range--a barricade (shadowing the areas between 225° and 285°) and a hill (between 345° and 45°). For reference, flat terrain was located between 135° and 195°. None of the data approach the current standard of 1250 feet. The flat terrain was 18% below this figure. However, if the flat terrain data is taken as a new standard, the reductions caused by the hill and the barricade can be computed. The range in the direction of the hill is reduced 36%, while in the direction of the barricade, the reduction is 42%.

1985 Radford Accident

NOTE: The following analysis was performed on data that was assembled by Paul E. Montanaro of the Naval Surface Warfare Center.

In February 1985, an accident occurred at the RADFORD Army Ammunition Plant, destroying a building. Debris maps of the area were prepared. However, a catalog giving the locations (range and azimuth or map coordinates) and descriptions of each individual piece was not prepared. The ranges and azimuths for each piece of debris was inferred from its location on the debris maps. It was further assumed that every piece was hazardous. Eight recovery sectors (45° apart) with widths of 30° were overlaid on the debris maps. With these assumptions, the raw data presented in Table 6 were prepared. When this information was analyzed with the procedures described above, the pseudo-trajectory-normal densities shown in Table 7 were obtained. The curve fitting procedures yielded the debris hazard ranges shown in Table 8 and Figure 3.

SUMMARY

A new procedure for approximating trajectory-normal densities from ground surface debris pickup is described and analyzed.

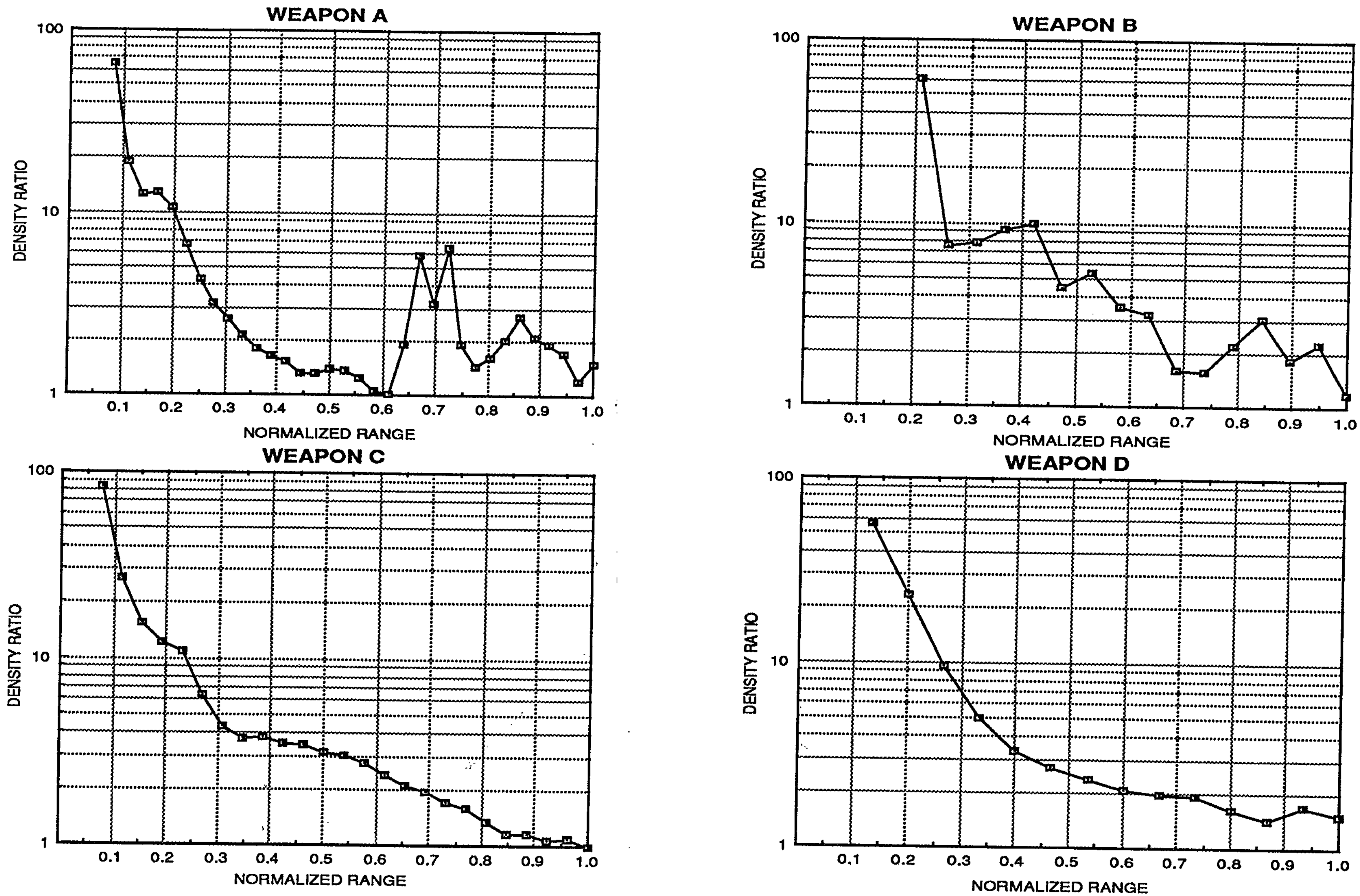
A set of standardized procedures have been developed for the analysis of explosion produced debris. The use of these procedures should greatly enhance the amounts and types of information which can be obtained from debris investigations.

REFERENCES

1. Department of Defense Ammunition and Explosives Safety Standards, DOD 6055.9-STD, First Amendment (Change 2), 28 October 1988.

2. McCleskey, F., "Quantity-Distance Fragment Hazard Computer Program (FRAGHAZ)," NSWC TR 87-59, February 1988.

3. Swisdak, Michael M., Jr., " Analysis of the Debris Produced By A Processing Building Accident," Minutes of the Twenty-Third Explosives Safety Seminar, 9-11 Aug 1988.



(NOTE: DENSITY RATIO=TRAJECTORY-NORMAL DENSITY/GROUND SURFACE DENSITY)

FIGURE 1 TRAJECTORY-NORMAL VERSUS GROUND SURFACE DENSITY

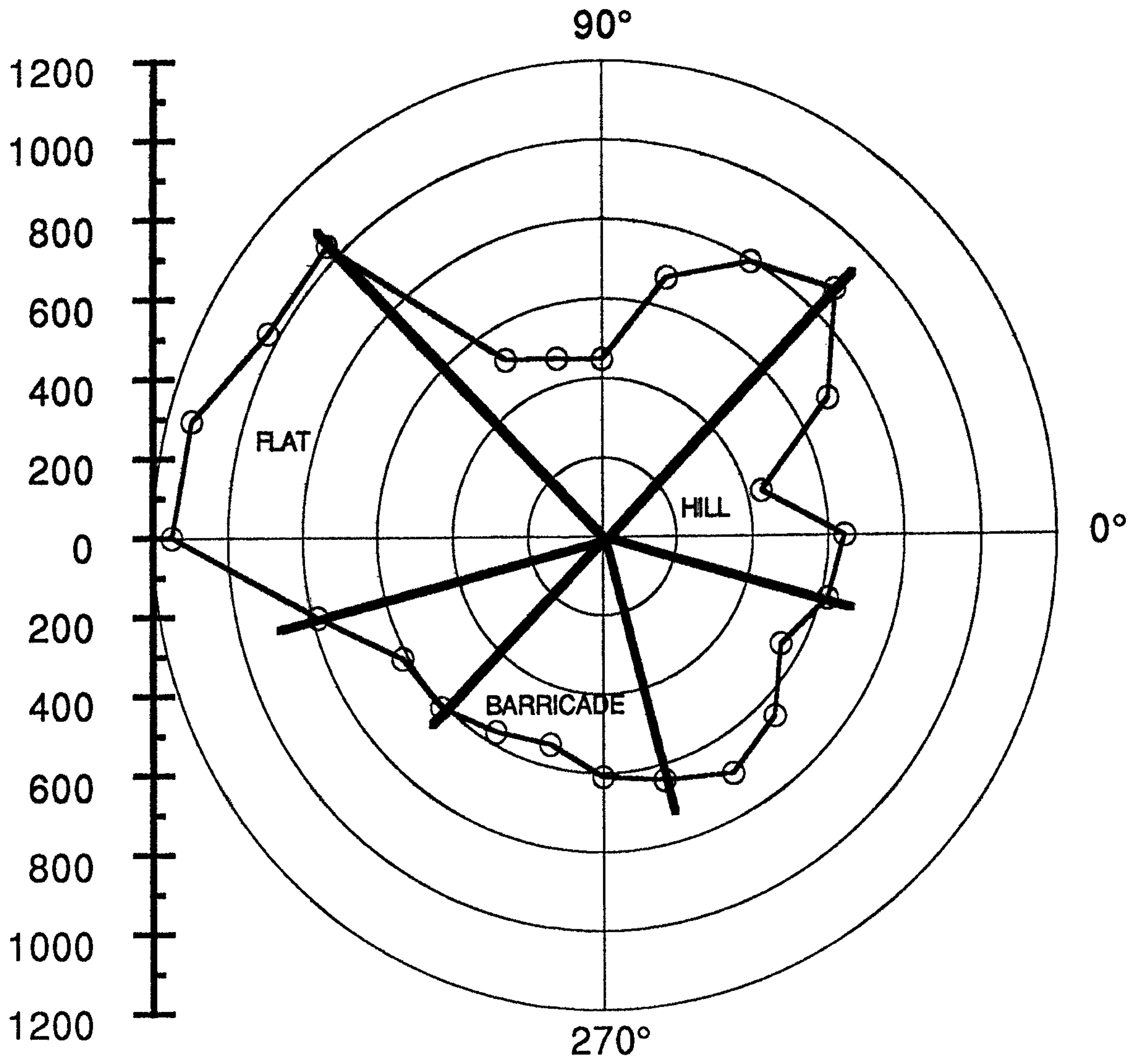


**FIGURE 2 PROCESSING BUILDING ACCIDENT--
DEBRIS HAZARD RANGE CONTOUR**

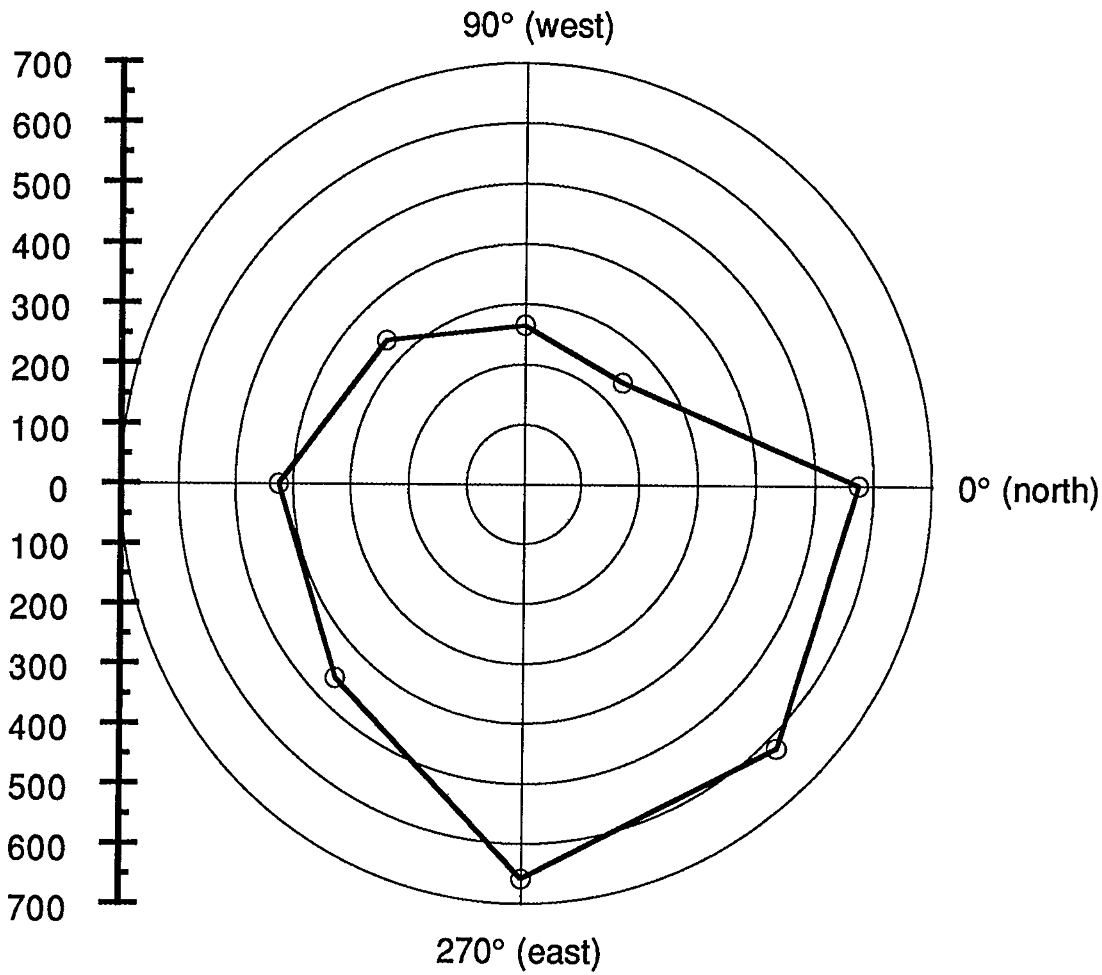


FIGURE 3 RADFORD ACCIDENT--
DEBRIS HAZARD RANGE CONTOUR

TABLE 1 COMPARISON OF TRAJECTORY NORMAL AND REVISED GROUND SURFACE PICKUP

WEAPON	RANGE TO A DENSITY OF 1 PER 600 FT^2 (ft)	RANGE TO A DENSITY OF 1 PER 600 FT^2 (ft)	PERCENT DIFFERENCE
	TRAJECTORY NORMAL	PSEUDO-TRAJECTORY-NORMAL	
A	1767 (1698-1835)*	2025 (1991-2059)*	14.60
B	1408 (1381-1434)*	1554 (1510-1599)*	10.37
C	1259 (1207-1309)*	1459 (1404-1515)*	15.89
D	718 (650-780)*	776 (716-835)*	8.08
		AVERAGE PERCENT DIFFERENCE	12.23

*95% confidence interval

TABLE 2 PROCESSING BUILDING ACCIDENT--NUMBER OF FRAGMENTS PER CELL

									1.0		1.0	0.5	0.5																		
										2.0	2.0	1.0				1.0	1.0				1.0										
							2.0	2.0	1.0	1.0	1.0		1.0		2.0		1.0	1.0	2.0	1.0	1.0										
		2.0				1.0	1.0	2.0	1.0	4.0	1.0	3.0	4.0	4.0	3.0	4.0	6.5	5.0	3.0	4.0	7.0	5.0									
		1.0	1.0	1.0			2.0	2.0	1.0	3.0	5.0	5.0	3.0	3.0	2.0	9.0	0.5	5.0	8.0	3.0	7.0	6.0									
			2.0			4.0	2.0	1.0	2.0	3.0		4.0	1.0	2.0	5.0	4.0	6.0	10.0	3.0	4.0	4.0	2.0									
				2.0	2.0	1.0			2.0	5.0	7.0	1.0	10.5	6.5	7.0	16.0	7.0	3.0	4.0	10.0	5.0	4.0	1.0								
				4.0				3.0	1.0	2.0	5.0	4.0	3.0	4.0	3.0	9.0	6.0	5.0	5.0	5.0	4.0	2.0		1.0							
		1.0		12.0	1.5	4.5	5.0	6.0	12.0	4.0	15.0	6.0	3.0	5.0	7.0	6.0	2.0	3.0	3.0	3.0	8.0	4.0									
	4.0	2.0	4.0	14.0	9.0	10.0	3.0	4.0	8.0	7.0	14.0	11.0	20.5	4.5	5.0	7.0	4.0	1.0	5.0	6.0	9.0		0.5	0.5							
	1.0	2.0	1.0	1.0	7.0	5.0	10.0	13.0	1.0	3.0	10.0	5.0	21.0	9.0	11.0	11.0	8.0	4.0	2.0	3.0	2.0	1.0	1.0								
			2.0	4.0	5.0	24.0	21.0	3.0	11.5	7.5	7.0	6.0	12.0	14.0	6.0	9.0	3.0	3.5	1.0		2.0			1.0							
2.0	1.0			6.0	4.0	13.0	21.0	32.0	16.0	32.0	3.0	6.0	5.0	15.0	14.0	20.0		0.5	2.0	1.0											
			1.0	5.0	5.0	13.0	18.0	46.0	26.0	28.0	19.0			17.0	11.0	19.0	6.0														
			6.0	2.0	4.0	5.0	21.0	18.0	49.0	13.0	22.0			55.0	15.0	15.5	17.0														
				1.0	1.0	2.0	40.0	6.0	7.0	10.0	31.0	17.0	61.0	80.0	14.0	12.5	12.0	5.0													
	1.0	1.0		2.0	2.0	1.0	10.0	9.0	31.0	4.0	5.0	28.5	92.0	45.5	26.0	12.0	3.0	6.0													
			2.0	5.0	8.0		1.0	3.0	12.0	3.0	3.0	17.0	41.5	60.0	28.5	11.0		2.0		1.0		4.0									
		1.0		4.0	2.0		0.5	4.0	24.0	26.0	44.0	18.0	20.0	45.0	25.0	8.0	11.0			2.0											
		2.0		1.0	4.0	5.0	8.5	10.0	18.0	59.0	86.5	78.5	81.5	18.5	15.5	9.0	7.0	1.0				1.0	2.0				1.0	1.0			
		1.0		1.0	2.0	3.0	2.0	14.0	18.0	258.5	95.5	105.0	82.5	38.0	29.0	20.0	22.0	1.0	6.0	2.0								1.0			
				1.0	2.0	2.0	2.0	3.0	6.0	8.0	61.0	68.0	84.0	75.0	23.0	10.0	9.0	6.0	3.0	2.0	3.0						1.0	1.0			
1.0					3.0	1.0	1.0	2.0	1.0	1.0	14.0	36.0	45.0	38.0	21.0	19.0	12.0	6.0	2.0	2.0	4.0						1.0				
				2.0	1.0				2.0	1.0	15.0	38.0	39.0	35.0	20.0	7.0	6.0	2.0			3.0	2.0	1.0	6.0	7.0						
				1.0					1.0	2.0	3.0	6.0	22.0	14.5	9.5	7.0	8.0	5.0		1.0	4.0	6.0	1.5	0.5		5.0	6.0	2.0			
		0.5				1.0			1.0		8.0	13.0	22.0	12.0	13.0	7.0	7.5	5.0	2.0	2.0	3.0		2.0	5.0	2.0		4.0				
		0.5			3.0	1.0			2.0	3.0	5.0	9.0	9.0	6.0	12.0	4.0	5.0	4.0		3.0	2.0	1.0	6.0	6.0	3.0	2.0	2.0	2.0			
		1.0					1.0		2.0		1.0		7.0	6.0	5.0	1.0	1.0	2.0	4.0	1.5	4.0	4.0			2.0	1.0	6.0	1.0			
											0.5	2.5		2.0	2.5				1.0	0.5	1.0		3.0	8.0			1.0	3.0			
										1.0				2.0	5.5				1.0			6.0	6.0	1.0		1.0	4.0				
								1.0				1.0	2.0	1.0	1.0	2.0	2.0										2.0				
							1.0	1.0				1.0					2.0		1.0	1.0	1.0	2.0		1.0				1.0			
												1.0								1.0	0.5	2.5			2.0	1.0					
							2.0													2.0					1.0			1.0			
																		0.5	0.5	1.0		1.0						3.0		2.0	
																1.0			3.0	1.0			1.0		1.0						
										1.0										1.0										1.0	
												1.0																			2.0
																												1.0			
																	0.5	1.0	0.5												

NOTE: EACH CELL REPRESENTS AN AREA OF 100' X 100'

TABLE 3 PROCESSING BUILDING ACCIDENT--NUMBERS OF FRAGMENTS VERSUS RANGE AND AZIMUTH

Lower Radius (ft)	Upper Radius (ft)	AZIMUTH (°) 0°	15°	30°	45°	60°	75°	90°
200	300	6.00	13.40	14.60	14.50	12.80	10.56	17.00
300	400	5.00	16.40	12.56	9.08	10.40	20.32	11.00
400	500	11.00	9.70	7.80	11.00	8.52	15.70	19.00
500	600	6.00	0.53	5.00	6.86	6.12	4.12	6.00
600	700	4.00	1.43	3.88	2.98	6.84	4.08	
700	800	1.00	0.98	3.44	3.50	12.20	6.55	
800	900	4.00	0.88	5.78	4.92	7.74	5.09	
900	1000	5.00	1.12	7.16	6.96	4.64	2.20	
1000	1100	3.00	0.29	3.84	5.60	4.35	3.00	
1100	1200	0.00	0.58	0.68	5.40	3.02	1.04	
1200	1300	1.00				1.22		
1300	1400	0.50						
1400	1500							
1500	1600							

Lower Radius (ft)	Upper Radius (ft)	AZIMUTH (°) 105°	120°	135°	150°	165°	180°	195°
200	300	39.32	60.24	70.68	75.71	72.13	28.50	16.77
300	400	14.27	16.72	36.14	55.58	46.55	17.00	4.52
400	500	13.45	11.69	25.25	47.12	25.65	18.00	38.10
500	600	8.64	2.64	10.44	24.80	53.78	78.50	73.08
600	700	2.62	2.16	9.14	16.24	46.90	105.00	189.65
700	800		0.32	5.42	20.72	68.92	68.00	8.00
800	900		1.40	1.48	9.60	32.00	36.00	1.28
900	1000		0.40	4.74	12.46	24.88	38.00	1.34
1000	1100		1.44	2.28	5.16	9.90	6.00	1.38
1100	1200		0.64	2.60	5.05	11.80	13.00	1.00
1200	1300			3.32	3.22	7.84	9.00	
1300	1400			3.04	1.12	1.80	0.00	
1400	1500			3.75	2.10		2.50	
1500	1600			2.56	1.22			

Lower Radius (ft)	Upper Radius (ft)	AZIMUTH (°) 210°	225°	240°	255°	270°	285°	300°
200	300	12.24	13.48	10.30	27.40	27.00	26.88	28.84
300	400	3.70	14.08	9.88	28.20	59.00	27.84	14.65
400	500	13.08	15.28	8.40	16.16	32.00	30.68	8.80
500	600	23.06	3.76	8.44	22.14	15.50	17.56	16.54
600	700	16.08	2.30	0.72	1.58	9.00	10.40	9.12
700	800	12.94	7.38	3.80	1.48	5.00	4.72	7.40
800	900	2.56	3.34	3.58	0.82	3.00	3.32	9.84
900	1000	1.08	2.08	2.08	0.42	0.50	1.00	7.00
1000	1100	0.12	1.40	0.22	0.58		0.78	0.80
1100	1200		0.06	1.34			0.32	0.32
1200	1300							
1300	1400							
1400	1500							
1500	1600							

Lower Radius (ft)	Upper Radius (ft)	AZIMUTH (°) 315°	330°	345°
200	300	20.80	6.45	6.32
300	400	4.64	5.71	9.40
400	500	4.54	4.34	12.42
500	600	8.58	8.80	10.30
600	700	3.60	9.12	3.18
700	800	4.77	2.76	4.58
800	900	1.47	0.00	2.88
900	1000	0.48	1.62	2.06
1000	1100	2.00	1.60	1.40
1100	1200	0.88	0.52	1.06
1200	1300	1.42		0.20
1300	1400	1.22		0.32
1400	1500	0.68		
1500	1600			

TABLE 4 PROCESSING BUILDING ACCIDENT--PSEUDO-TRAJECTORY NORMAL DEBRIS DENSITY VS. AZIMUTH

RADIUS	AZIMUTH (°)											
(ft)	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°
250	2.79	2.72	3.88	4.25	4.55	4.36	3.18	4.70	5.86	10.85	16.81	24.13
350	2.43	1.91	3.01	3.38	3.78	3.73	2.16	2.34	2.24	6.61	12.26	19.80
450	2.13	0.93	2.25	2.83	3.16	2.51	1.50	1.48	1.24	4.44	8.93	17.01
550	1.47	0.35	1.79	2.17	2.77	1.56	0.36	0.68	0.54	2.93	6.10	15.47
650	1.11	0.32	1.49	1.76	2.40	1.32		0.16	0.38	2.30	4.61	12.24
750	0.87	0.23	1.25	1.58	1.99	1.07			0.25	1.75	3.64	9.43
850	0.81	0.17	1.05	1.37	1.26	0.68			0.23	1.43	2.40	5.29
950	0.57	0.12	0.70	1.08	0.79	0.37			0.15	1.34	1.82	3.37
1050	0.27	0.05	0.27	0.66	0.52	0.24			0.12	1.05	1.07	1.88
1150	0.09	0.03	0.04	0.32	0.25	0.06			0.04	0.92	0.76	1.29
1250	0.09				0.07					0.76	0.46	0.58
1350	0.03									0.56	0.27	0.11
1450	0.03									0.38	0.20	
1550	0.03									0.15	0.07	

RADIUS	AZIMUTH (°)											
(ft)	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
250	25.17	20.11	5.09	3.79	2.93	5.93	9.06	7.41	6.20	3.30	2.46	3.25
350	23.46	19.10	4.36	2.98	2.31	4.28	7.44	5.80	4.47	2.06	2.07	2.87
450	22.44	18.83	4.14	2.14	1.71	2.59	3.90	4.13	3.59	1.78	1.73	2.30
550	21.36	16.54	3.35	1.22	1.21	1.62	1.98	2.29	3.06	1.51	1.47	1.56
650	16.65	12.16	1.97	0.99	0.70	0.29	1.05	1.23	2.07	0.99	0.94	0.94
750	10.35	0.78	1.00	0.86	0.66	0.20	0.51	0.61	1.52	0.78	0.39	0.75
850	6.27	0.30	0.23	0.41	0.43	0.11	0.21	0.33	1.08	0.49	0.22	0.48
950	4.11	0.22	0.07	0.21	0.22	0.06	0.03	0.13	0.49	0.40	0.22	0.30
1050	1.83	0.14	0.01	0.09	0.09	0.03		0.07	0.07	0.37	0.13	0.18
1150	1.47	0.06			0.08			0.02	0.02	0.25	0.03	0.09
1250	0.69									0.20		0.03
1350	0.15									0.11		0.02
1450	0.15									0.04		
1550												

TABLE 5 PROCESSING BUILDING ACCIDENT--DEBRIS RANGES

(NOTE: based on pseudo-trajectory normal densities)

AZIMUTH (°)	DEBRIS HAZARD RANGE (ft)	TERRAIN FEATURE	AVERAGE (ft)
345	617	HILL	653
0	642	HILL	
15	439	HILL	
30	691	HILL	
45	875	HILL	
60	796		
75	674		
90	447		
105	464		
120	514		
135	1037	FLAT	1027
150	1028	FLAT	
165	1136	FLAT	
180	1149	FLAT	
195	786	FLAT	
210	615		
225	609	BARRICADE	594
240	569	BARRICADE	
255	544	BARRICADE	
270	609	BARRICADE	
285	639	BARRICADE	
300	694		
315	647		
330	547		

FLAT TERRAIN : 1027 ±156 FEET
HILL: 653 ±146 FEET
BARRICADE: 594 ±37 FEET

NOTE: where not noted, the terrain is mixed and varied.
MIXED: 600 ±116 FEET

TABLE 6 RADFORD ACCIDENT--NUMBERS OF FRAGMENTS VERSUS RANGE AND AZIMUTH

LOWER RADIUS (ft)	UPPER RADIUS (ft)	AZIMUTH (°) 0	45	90	135	180	225	270	315
0	100	80	57	10	30	25	121	17	39
100	200	35	2	1	13	4	3	3	12
200	300	23	7	0	6	23	1	9	8
300	400	20	3	8	5	15	9	21	20
400	500	11	0	4	2	13	15	31	18
500	600	8	1	4	4	4	10	16	24
600	700	19	0	3	3	3	7	17	16
700	800	4	2	0	3	2	5	22	10
800	900	1	1	0	2	4	2	17	6
900	1000	6	0	0	0	0	3	7	1
1000	1100	2	0	0	0	1	1	6	4
1100	1200	1	0	0	0	1	0	4	4
1200	1300	0	0	0	0	0	0	2	4
1300	1400	3	0	0	0	0	0	1	0

TABLE 7 RADFORD ACCIDENT–PSEUDO-TRAJECTORY NORMAL DEBRIS DENSITY VERSUS AZIMUTH

AVERAGE RADIUS (ft)	AZIMUTH (°)							
	0	45	90	135	180	225	270	315
50	48.82	16.73	6.88	15.58	21.77	40.57	39.65	38.04
150	10.16	1.22	1.53	2.90	5.35	4.28	11.92	9.70
250	4.49	0.64	0.87	1.15	3.03	2.43	7.01	5.27
350	2.46	0.23	0.62	0.62	1.41	1.70	4.71	3.50
450	1.40	0.10	0.28	0.36	0.71	1.09	3.13	2.22
550	0.92	0.08	0.15	0.25	0.31	0.58	1.92	1.44
650	0.63	0.05	0.05	0.14	0.19	0.32	1.34	0.79
750	0.26	0.05		0.08	0.12	0.17	0.90	0.44
850	0.18	0.01		0.03	0.08	0.08	0.50	0.26
950	0.14				0.02	0.05	0.24	0.16
1050	0.07				0.02	0.01	0.14	0.13
1150	0.04				0.01		0.07	0.08
1250	0.03						0.03	0.04
1350	0.03						0.01	

TABLE 8 RADFORD ACCIDENT--HAZARDOUS DEBRIS RANGE

AZIMUTH (°)	DEBRIS HAZARD RANGE (ft)
0	574
45	240
90	264
135	337
180	424
225	458
270	658
315	620